Experimental Investigation of Wear Mechanisms with Electroplated CBN Wheel

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Abstract

Wheel wear in grinding is a sophisticated phenomenon which can affect the whole grinding process profoundly. In this study, different types of wear mechanisms such as attritious wear, grain fracture and the pullout of the abrasive grains have been studied on a single layer electroplated cubic boron nitride (CBN) grinding wheel. The effect of wear mechanisms on the grinding forces and the workpiece surface have been taken into account. Surface grinding experiments were conducted on Inconel 718 and the change in the wheel topography and the grinding behavior were investigated. Grits were individually investigated and wear mechanisms on them are discussed. Individual grit investigation provides more detailed analysis of wear.

Introduction

Grinding of Inconel 718 with electroplated cubic boron nitride (CBN) wheels will be more general in today's aerospace industry because of its significant advantages compared to conventional wheels [1-3]. The cutting action by these wheels is achieved by randomly distributed grains over electroplated nickel bond. Because of the single layer formation dressing or truing cannot be carried out on these wheels. Thus, the wheel life and grinding performance are considerably restricted by wear since the changes in the wheel topography directly affect the process. Accordingly studying the wear behavior of this kind of wheel is highly important to improve grinding performance.

Wear in conventional grinding wheels can occur due to three mechanisms, namely attritious wear, fracture of the grits and bond fracture [4,5]. Different grinding wheel-workpiece pairs show different dominant wear trends. For example, E.J. Duwell showed that the dominant wear mechanism for silicon carbide grits for cutting mild steel is attritious while both attritious and fracture wear occurred for aluminum oxide grits for the same work material [6]. Furthermore, there are some studies showing the changes in the wear mechanisms during the wheel life which provides more specific and detailed analysis of wear mechanisms. Shi and Malkin clarified that most of the wear caused by pullout during the initial stages of the wheel life and fracture is dominant wear mechanism in steady-state regime [7]. Attritious wear causes dulling of the grits which results in enhancing grinding power. So that temperature escalates and most of the heat flows towards the wheel instead of workpiece [8].

In the previous studies, attritious wear was measured via microscope by using the reflection of light [1,2]. Fracture of the grits was measured under the name of bond and grain fracture via weight calculation [5]. Pullout mechanism was measured by counting the pockets in the surface via microscope [9]. The present study presents individual changes of grits.

In this paper, more detailed analysis of wheel wear mechanisms in the electroplated CBN wheels are experimentally investigated with regards to attritious, fracture and pullout. The objective is to understand the effect of the wheel-workpiece interaction on the grits by investigating wear behavior *individually.* Since cutting force is an important indicator of wear mechanism [1], force measurements are used to monitor the wear.

Experimental Set-Up

In order to investigate the wear mechanisms of electroplated CBN wheels, surface grinding tests have been carried out on a Chevalier Smart B818III grinding machine while applying a 5% water-oil mixture. The tests were conducted on Inconel718 specimen with the dimensions of 55mm in length and 7mm in width which is shown in Fig. 1a. Table 1 shows the cutting conditions and detailed properties of the workpiece and the wheel. Cutting conditions have been specified according to literature and previous experiences [1-8].

Table 1- Cutting Conditions and Wheel & Workpiece Properties

Workpiece	Inconel 718 (31 HRC)
Wheel	Electroplated single layer 120 grit CBN wheel with diameter of 10 mm, width of 8 mm
Cutting speed [m/s]	18.85
Feed rate [mm/min]	250
Depth of cut [mm]	0.1
MRR [mm^3/s]	2.92
Specific MRR [mm^2/s]	0.42

The grinding tests were conducted for 150 passes. The number of passes has been determined according to the force and wear results during the tests. When an increase of 15% was observed in the force, the test was stopped and the wheel surface was measured. Grinding forces in feed and radial directions were measured by a Kistler dynamometer during every pass and average of the force data was used in order to see the effect of the wear on the force.

After 10, 25, 40 and 75 passes the grits of the wheel were observed via Nanofocus microscope and compared with the initial condition of the wheel. For this purpose, 30 individual grits were chosen randomly and at every 10, 25, 40 and 75 passes (henceforth referred to as step) the same grits were investigated on the microscope with magnification of 50 (0.1024 mm^2). The purpose of this measurement is to observe the specific changes on the grits individually. These changes are classified as fracture, attritious wear of the grit and no change. If the height of the grit is reduced and it has a flat rough surface, it is classified as attritious wear which can be seen in Fig. 6. If some part of the grit has been destroyed, it is classified as fracture which can be seen in Fig. 5. Also height changes of the grits were calculated by measuring surface and the tip of the flat face of the grits in order to observe radial wear. Observation of the same grits individually after each step is a direct method to see the more precise effect of workpiece-wheel interaction on the grits which was applied in this experimental work. Fig. 1b shows the setup in order to see the same grits after each step where the green light shows the focused area on the wheel. This setup provides a 360^o peripheral view of the wheel so that the whole peripheral surface can be seen step by step.

Furthermore, in order to observe the effect of the workpiece-wheel interaction on a larger area, lower magnification was also employed using a 20 x lens (0.64 mm^2 field of view). 10 areas were chosen and similar to the observations made in case of 30 individual grits, the same area was investigated after each step. This magnification was carried out in order to investigate pullout mechanism of the wheel. Pullout mechanism has been measured by analyzing the changes in reflection of the light on the grits. The black and grey colors indicate grits and ground, respectively. Here, ground refers to the measurement surface. If reflections were observed lower than the near ground reflections, that grit was called a pullout. Because of the circular shape of the wheel, it is not possible to focus whole area in one frame. Thus, all black dots have been investigated individually. During this method, when every point was selected on the surface, all other points as high as the selected point will be displayed with red color. Mentioned measurement can be applied to compare the level of grits. As is shown in Fig. 2, due to black color of displayed grits between red area, concludes that this grit is not at the same level as red area. In addition, when the mentioned grit is selected as the level of measurement, it was found to be at same level as the point previously perceived as being at lower level.

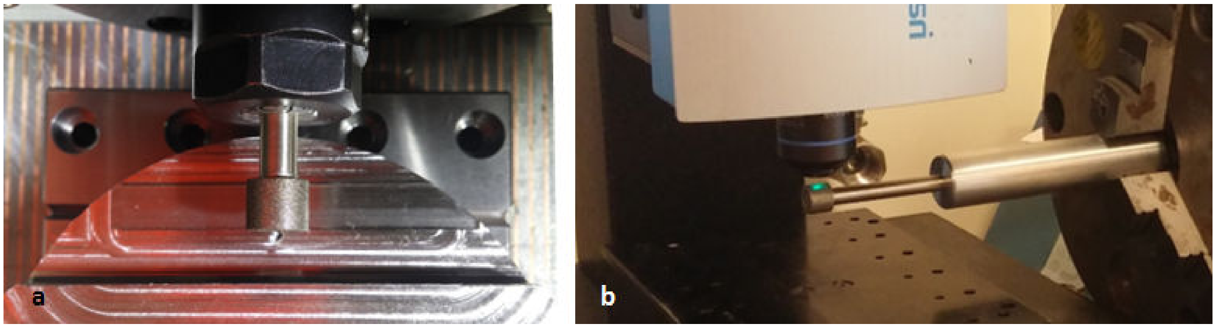

Figure 1- a) Test Setup, b) Nanofocus Measurement Setup

Surface roughness (Ra and Rz) of the wheel and the workpiece have also been measured after every step via Talysurf surface profile measurement device. By measuring the wheel surface profile, radial wear can be identified. Measuring height change of the grits individually can also be used to determine the radial wear. Both methods provide close results for radial wear.

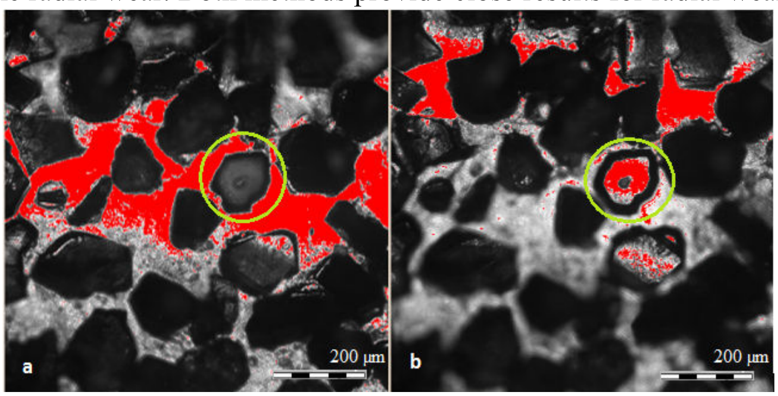

Figure 2-Pullout Measurement; a) Focused on Higher height, b) Focused on Lower Height

Results and Discussion

Pullout Mechanism

In Fig. 3, surface topography is given after each step where a step consists of a specific number of passes as defined earlier in experimental setup. During individual investigation of the black areas, some black points were found to be lower than the surface, so their condition needed to be further evaluated. In order to examine the same, a comparison of the wheel surface after every cutting test was made by marking the black dots with two different colors. If a black point was found as being lower than the surface, it was represented through a turquoise dot. If the point was found to be higher than the near ground it was marked with a blue dot. The increase in the turquois dots can be seen clearly in Fig. 3.

Table 2- Grit and Pullout Numbers in 0.64 mm^2 Area After Each Step

AMR (mm^3)	0		385		1347.5		3272.5		7892.5	
Position (deg)	Grit	Pullout	Grit	Pullout	Grit	Pullout	Grit	Pullout	Grit	Pullout
0	29	0	28	1	28	1	28	1	28	1
36	31	0	27	4	26	5	25	6	25	6
72	27	0	26	1	26	1	25	2	25	2
108	25	0	22	3	21	4	21	4	21	4
144	27	0	26	1	26	1	24	3	24	3
180	25	0	25	0	25	0	25	0	24	1
216	32	0	30	2	29	3	29	3	29	3
252	29	0	28	1	24	5	24	5	24	5
288	31	0	24	7	24	7	23	8	23	8
324	23	0	20	3	20	3	20	3	20	3
TOTAL	279	0	256	23	249	30	244	35	243	36

Grit and pullout numbers are given in Table 2 for 10 different selected areas. Although all pullout numbers at the beginning seem zero, initial condition of the tool has some pullouts. While counting the grits, initial pullouts have considered as none and counting of pullouts started after first cutting test. It can be observed that in some regions there is almost no pullout.

Fig. 4 shows the number of grits pulled out during the tests. It can be seen from the figure that in the initial stages corresponding to low accumulated MR, there are considerably large number of pulled out grits in a short time. After some time, number of pulled out grits saturates as there are almost no grits pulled out during the remaining passes. This can be explained by this fact that there is a low bonding force between some grits and the wheel due to the manufacturing process of the wheel and they are pulled out due to the grinding forces acting on them.

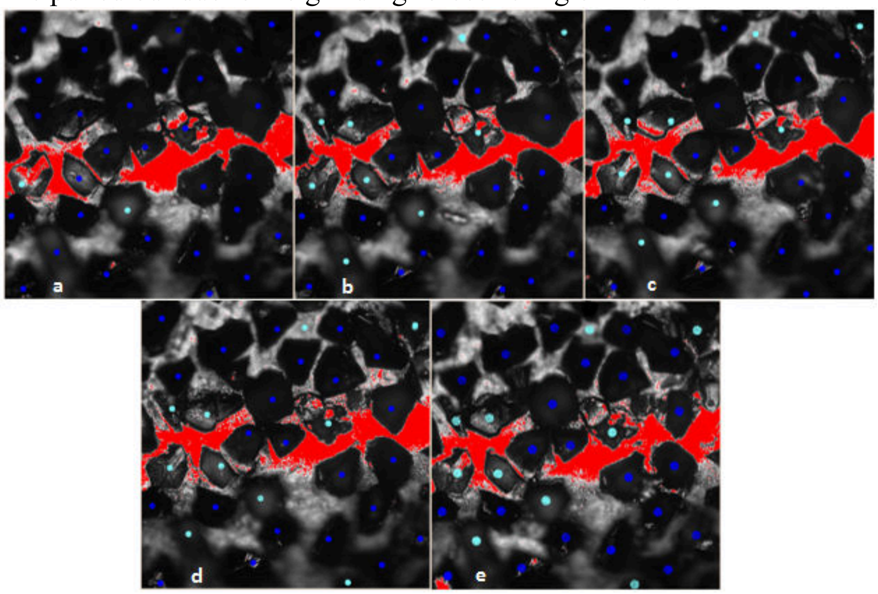

Figure 3- Pullout Mechanism in Steps; a)Before Test, b)After 10 passes, c)After 35 passes, d)After 75 passes, e)After 150 passes

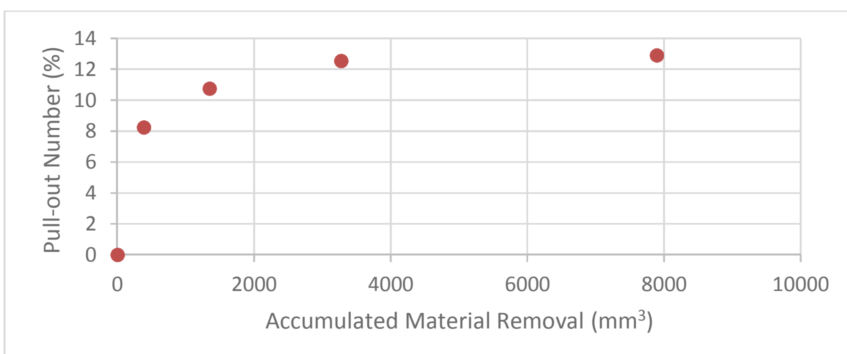

Figure 4- Change in the Pullout Number

Fracture Mechanism & Attritious Wear

Fracture mechanism is defined as losing some part of the grit. After investigation of 30 grits, it was observed that while some of them had attritious wear, some others had fracture and some did not change at all. Among the investigated grits, 14.7% of them seemed to have fracture after 150 passes. Fracture mechanism can be seen in Fig. 5.

On the other hand, it was observed that 61.8% of the grits had attritious wear. Their heights were shortened 27% after 150 passes and had rough flat top section. The reduction of the height can be seen in Fig. 6. The initial and the last state of one grit is given and the destroyed part of the grit is shown. The percentage distribution of attritious and fracture wear mechanisms are shown in Fig. 7.

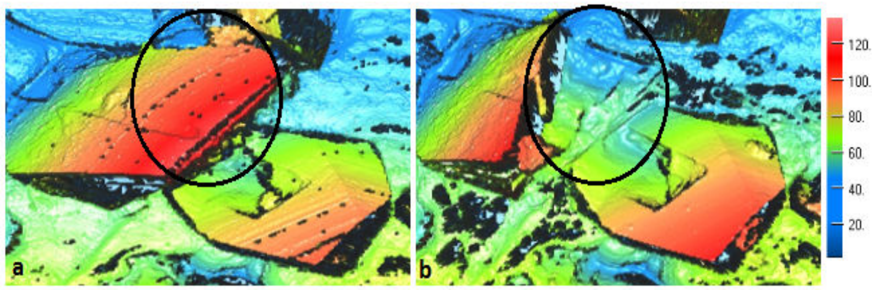

Figure 5- Fracture On a Single Grit; a) Initial State, b) After 150 Passes

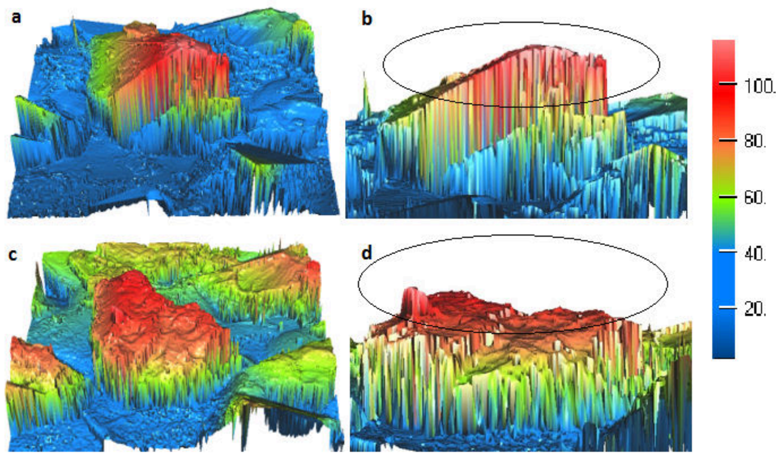

Figure 6- Attritious Wear on a Single Grit; a) Initial State, b) Front View of Initial State, c)After 150 passes, d) Front View of After 150 Passes

Radial Wear of the Wheel and Surface Roughness of the Wheel and Workpiece

Height changes of the 30 grits were measured individually after each step via Nanofocus with 50x lens and the results are shown in Fig. 11. Before the test it was observed that the average height of 30 grits was approximately 60.7 µm. At the end the average height measured as 44.3 µm. The change in the height is 27%.

On the other hand, wheel surface topography was also measured in terms of Ra and Rz after every cutting test which can be seen in Fig. 9 and 10. Ra and Rz changes before starting the cutting and after 150 passes were observed as 26.8 % and 25.2%, respectively. The height changes of grits have been measured by two techniques. First one is by looking grits individually. The second one is by looking Ra and Rz values of the wheel. It was found that both of them provided very close results. It means that considering 30 grits to study wear mechanism was sufficient to represent the behavior of grits for the whole wheel in this work. Height changes of the grits after each step are presented in Fig. 11.

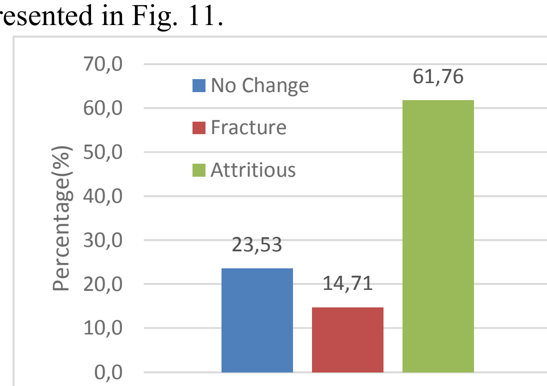

Figure 7- Percentages of Grit Wear Mechanisms

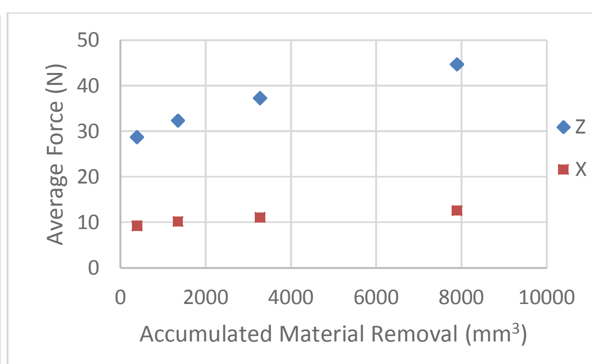

Figure 8- Average Forces During Tests

Surface roughness Ra measurements of the wheel and workpiece can be seen in Fig. 9. Both of them decrease with increased accumulated material removal as expected [2].

Effect of Wear on Grinding Force

Grinding forces in the tests are directly affected by wear of the wheel. During cutting tests average forces were measured and effect of the wear on forces is shown in Fig. 8. Forces have increasing trend as most of the cutting edges of the grits were dulled because of attritious wear. So, grits can not penetrate workpiece easily. Force is increased 55.6% at the end of the tests compared to the first step. It should be mentioned that there was a noise due to coolant and vibration of the spindle. Magnitude of the noise was around 3 N.

During the measurements of individual grits; although coolant was used, it was observed that some chips were stuck between the grits. This situation has been considered in measurements.

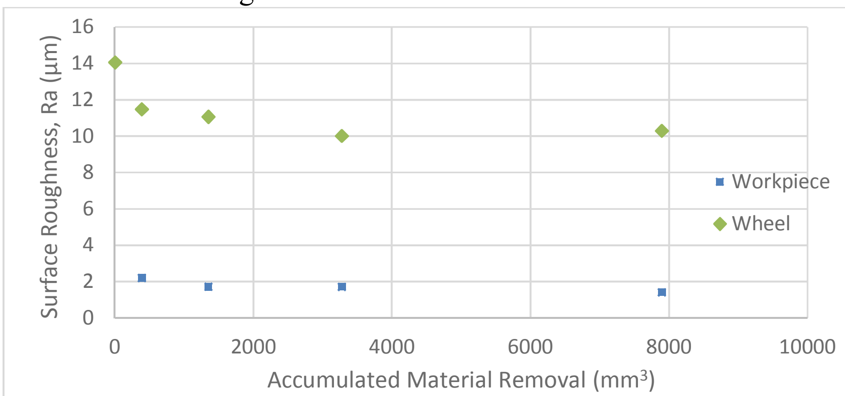

Figure 9- Surface Roughness (Ra) of the Wheel & Workpiece

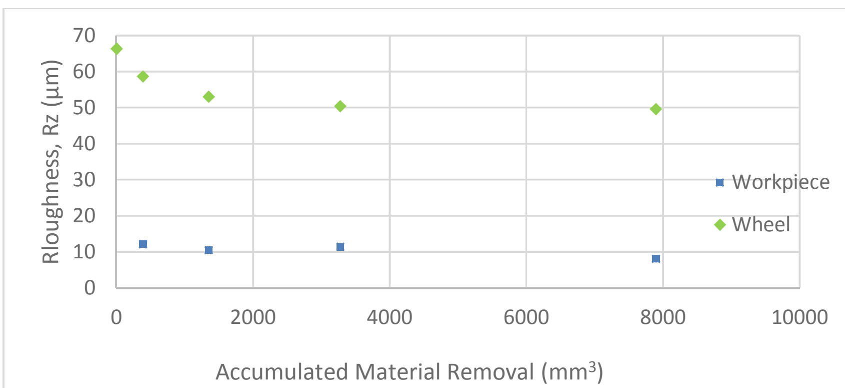

Figure 10- Surface Roughness (Rz) of the Wheel & Workpiece

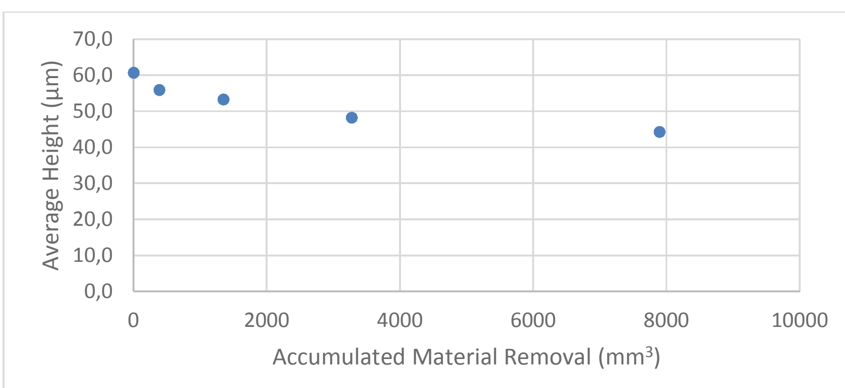

Figure 11- Average Height Changes of the Grits After Each Step

Conclusion

This paper presents an individual investigation method for grits in electroplated CBN tools. By this method, attritious and fracture wear can easily be seen. Two separate methods were used for radial wear. First one was observing the changes in average heights of 30 grits. The second one is measuring the surface roughness of the wheel by a profile measurement device. Both of those measurements were compared and it was observed that they yielded very close results. It was found out that attritious wear was more dominant wear mechanism than fracture wear throughout the process, which can be seen in Fig. 7 in detail. On the other hand, pullout mechanism was effective in the early stages of the grinding as some grits have low bonding force. Surface roughness of the workpiece showed a declining trend because of the decreasing grits heights' due to attritious wear. Force results showed an increasing behavior because of dulling of the grits.

Contrary to literature [2], attritious wear is considered as micro fractures and particle losses due to friction on the grit. In the scope of this work, attritious wear can be thought as height decrement without being exposed to instant high loss of a part of a grit, on the other hand, the other wear mechanism "fracture" is defined as loss of a huge part of a grit suddenly. In conclusion, attritious wear has been found more dominant wear mechanism under specified cutting conditions.

In the future research, the importance of the active grits will be investigated individually. In order to have a better opinion, the effect of different cutting parameters on wear mechanism will be analyzed. Volumetric changes of the grits will also be investigated individually.

Acknowledgements

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References:

[1] P. L. Tso, Study on the grinding of Inconel 718, Journal of Materials Processing Technology 55 (1995) 421-426.

[2] Z. Shi, S. Malkin, Wear of Electroplated CBN Grinding Wheels. ASME. J. Manuf. Sci. Eng. 128 (2005) 110-118.

[3] C. Guo, Z. Shi, H. Attia, D. McIntosh, Power and Wheel Wear for Grinding Nickel Alloy with Plated CBN Wheels, Annals of the CIRP Vol. 56/1/2007 343-346.

[4] S. Malkin, and N. H. Cook, The Wear of Grinding Wheels Part I: Attritious Wear, ASME J. Eng. Ind., 93 (1971) 1120–1128.

[5] S. Malkin, and N. H. Cook, The Wear of Grinding Wheels Part II: Fracture Wear, ASME J. Eng. Ind., 93 (1971) 1129–1133.

[6] E. J. Duwell, W. J. McDonald, Some Factors That Affect the Resistance of Abrasive Grits To Wear, Wear 4 (1961) 372-383.

[7] Z. Shi, S. Malkin, 2006, An Investigation of Grinding with Electroplated CBN Wheels, Annals of the CIRP, 52/1:267-270.

[8] R. P. Upadhyaya, and S. Malkin, 2004, "Thermal Aspect of Grinding WithElectroplated CBN Wheels," ASME J. Manuf. Sci. Eng., 126, 107–114.

[9] R. P. Upadhyaya, J. H. Fiecoat, Factors Affecting Grinding Performance with Electroplated CBN Wheels, Annals of the CIRP Vol. 56/1/2007 339-342.